Gamma Ray Bursts Cannot Produce the Observed Cosmic Rays Above 10^{19} eV

F. W. Stecker

Laboratory for High Energy Astrophysics, Code 661, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA.

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ABSTRACT

Using recent results indicating that the redshift distribution of γ-ray bursts most likely follows the redshift evolution of the star formation rate, I show that the energy input from these bursts at low redshifts is insufficient to account for the observed flux of ultrahigh energy cosmic rays with energies above 10^{19} eV.

Subject Headings: gamma-rays: bursts — cosmic rays: theory

1. Introduction

Waxman (1995a,b) and Vietri (1995) have suggested that cosmological γ-ray bursts can produce the observed flux of cosmic rays at the highest energies. The arguments as stated by Waxman (1995b) rest on four assumptions: (1) the highest energy cosmic rays are extragalactic, (2) cosmic rays can be accelerated to these energies in γ-ray burst fireballs, (3) the energy emitted by the bursts in ultrahigh energy cosmic rays is roughly equal to the electromagnetic energy emitted by the bursts (primarily in hard X-rays and soft γ-rays), and (4) the bursts have comoving density distribution which is independent of redshift, *i.e.* there is no cosmological evolution.

While neither accepting or addressing assumptions (2) and (3), in this Letter, I will argue that assumption (4) has become implausible when one considers the recent redshift information obtained by locating the afterglow radiation from the bursts in host galaxies with measured redshifts. These studies place almost all γ-ray bursts (GRBs) with redshift assignments at moderate or high redshifts. Host galaxy studies imply that the GRB redshift distribution should follow the strong redshift dependence of the star formation rate in galaxies (see section 3 below). A further implication is that the spatial density of γ-ray bursts at low redshifts would be too low to produce the observed flux of cosmic rays above 10^{19} eV. The argument becomes much stronger for the cosmic rays above 10^{20} eV, since those cosmic rays can only reach us unattenuated in energy from distances of ~ 200 Mpc or less (Stecker 1968; Stecker & Salamon 1999), corresponding to redshifts $z \leq 2.5 \times 10^{-2}$.

2. The Energetics Argument for Non-evolving GRBs

If one assumes that GRBs have a redshift independent co-moving distribution, the energetics argument of Waxman (1995a,b) can be summarized quite succinctly. If one takes the observed rate of GRBs and averages it out over the volume of the observable universe, one finds an average rate per unit volume of $r_{GRB} \simeq 4.5 \times 10^{-8} h^3$ Mpc^{-3}yr^{-1}. If one then takes an average energy release per burst of $10^{52} h^{-2}$ erg in γ-rays and equates this to the energy released in ultrahigh energy cosmic rays, one finds a cosmic-ray energy input rate into intergalactic space of $4.5 \times 10^{44} h$ erg Mpc^{-3}yr^{-1} $\simeq 3 \times 10^{44}$ erg Mpc^{-3}yr^{-1}. This is roughly equivalent to the energy flux per dex in ultrahigh energy cosmic rays at energies $\sim 10^{19}$ eV.

3. The Redshift Distribution of GRBs and its Implications

The advent of the *BeppoSAX* X-ray telescope and the discovery of GRB X-ray (Costa, *et al.* 1997), optical (Galama, *et al.* 1997) and radio (Frail, *et al.* 1997) afterglows and the subsequent identification of host galaxies has led to the determination of the redshifts of some 11 GRBs from 1997 to date. Of these, 10 are at moderate to high redshifts and the remaining one, GRB980425, has been identified with a nearby unusual Type Ic supernova, SN 1998bw (Galama, *et al.* 1998) with an energy release ($\sim 5 \times 10^{47}$ erg) which is orders of magnitude smaller than the typical cosmological GRB. (In fact, it is not completely established whether the supernova was indeed the source of the GRB, as another fading X-ray source was a possible contender (Pian, *et al.* 1999)). The GRB with the highest identified redshift to date, GRB971214, lies at a redshift of 3.42 (Kulkarni, *et al.* 1998).

The positions of the bursts within the host galaxies and their apparent association with significant column densities of hydrogen and with evidence of dust extinction (Reichert 1998; Kulkarni, *et al.* 1998) has led to their association with regions of active star formation. Analyses of the colors of various host galaxies of GRBs has indicated that these galaxies are sites of active star formation (Kulkarni, *et al.* 1998; Castander & Lamb 1999; Fruchter, *et al.* 1999) and this conclusion is strengthened by morphology studies and the detection of

[OII] and Lyα emission lines in several host galaxies (Metzger, *et al.* 1997; Bloom, *et al.* 1998; Kulkarni, *et al.* 1998).

The association of GRBs with active star formation, together with the known strong redshift evolution of the star formation rate (*e.g.*, Madau, Pozzetti & Dickenson 1998), has led to theoretical examinations testing whether a uniform comoving density redshift distribution or one which follows the star formation rate fits the GRB data best (Totani 1997,1998; Wijers, *et al.* 1998, Krumholz, Thorsett & Harrison 1998; Mao & Mo 1998). In particular, Mao & Mo (1998) give a thorough up-to-date discussion of the nature of the host galaxies of GRBs. I will adopt their results for my discussion in this Letter.

4. GRB Redshift Evolution Leads to a Strong Energetics Problem

Mao & Mo (1998) find that their best fit model corresponds to a GRB redshift distribution following the star formation rate which would have a *present rate* ($z \simeq 0$) of $\simeq 1.7 \times 10^{-10} h^3$ Mpc^{-3}yr^{-1} and a mean energy release of $\sim 10^{52} h^{-2}$ erg per burst. The corresponding energy release rate per unit volume would then be $\sim 1.4 \times 10^{42}$ Mpc^{-3}yr^{-1} (with $h = 0.7$). *This is about a factor of 200 below the rate needed to explain the ultrahigh energy cosmic rays* as indicated in Section 2 above.

5. Other Considerations

There are other considerations which support or tighten the thesis presented here that the GRBs do not produce the observed ultrahigh energy cosmic rays. Beaming is not a way out. While it is true that if GRBs are beamed into a solid angle Ω, we only see $(\Omega/4\pi)$ of them, the energy release per burst would also be lower by the same factor of $\Omega/4\pi$ and the total energy release rate per unit volume is unchanged. Also, if the evolving redshift distribution scenario for GRBs is correct, there will not be large numbers of faint GRBs nearby; the faintest GRBs seen will corrrespond to GRBs which are at the highest redshifts. (Even if the redshift distribution of bursts were more uniform than the star formation rate assumed here, this would imply that the average energy release per burst would be lower in order to fit the observed flux distribution, since there would be more nearby sources.)

Finally, I wish to comment on the cosmic rays seen above 10^{20} eV. Waxman (1995b) has argued that the present cosmic ray data may be still statistically consistent with a uniform GRB distibution in redshift, even though no cosmological cutoff is seen corresponding to the so-called GZK effect (Greisen 1966; Zatsepin & Kuzmin 1966; Stecker 1968). The GZK effect should manifest itself in a steepening of the cosmic ray spectrum above an energy of $\sim 7 \times 10^{19}$ eV (*e.g.*, Stecker 1989). If, as argued here however, the GRBs are cosmic ray sources at moderate to high redshifts, the GZK effect comes in at lower energies (by a factor of $(1 + z)^2$) and the attenuation will be much more severe since the GZK process involves cosmic ray energy loss from photopion production off the 3K cosmic background radiation (which would actually have a temperature of $3[1 + z]$K) and the photon (target) density of this background would be higher by a factor of $(1 + z)^3$. In fact, one expects to see *no* 10^{20} eV cosmic rays except those coming from redshifts, $z \ll 1$. This is in strong contradiction to the observations (Hayashida, *et al.* 1994; Bird, *et al.* 1995; Takeda, *et al.* 1998).

REFERENCES

Bird, D.C. *et al.* 1995, ApJ 441, 144

Bloom, J. *et al.* 1998, ApJ 507, L25

Costa, E. *et al.* 1997, IAU Circ. No. 6576

Costander, F.J. & Lamb, D.Q. 1998, in *Gamma Ray Bursts*, ed. C.A. Meegan, R.D. Preece & T.M. Koshut (New York: AIP) 520

Frail, D.A. *et al.* 1997, Nature 389, 261

Fruchter, A.S., *et al.* 1999, e-print astro-ph/9807295, ApJ, in press.

Galama, T.J. *et al.* 1997, IAU Circ. No. 6584

Galama, T.J. *et al.* 1998, Nature 395, 670

Greisen 1966, Phys. Rev. Letters 16, 748

Hayashida, N. *et al.* 1994, Phys. Rev. Letters 73, 3491

Kulkarni, S.R., *et al.* 1998, Nature 393, 35

Krumholz, M., Thorsett, S.E. & Harrison, F.A. 1998, ApJ 506, L81

Madau, P., Pozzetti,L. & Dickenson,M. 1998, ApJ 498, 106

Mao, S. & Mo, H.J. 1998, A & A 339, L1

Metzger, M. *et al.* 1997, Nature 387, 878

Pian, E. *et al.* 1999, e-print astro-ph/9910235, submitted to ApJ

Reichert 1998, ApJ 495, L99

Stecker, F.W. 1968, Phys. Rev. Letters 21, 1016

Stecker, F.W. 1989, Nature 342, 401

Stecker, F.W. & Salamon, M.H. 1999, ApJ 512, 521

Takeda, M. *et al.* 1998, Phys. Rev. Letters 81, 1163

Totani, T. 1997, ApJ 486, L71

Totani, T. 1998, e-print astro-ph/9805263

Vietri, M. 1995, ApJ 453, 883

Waxman, E. 1995a, Phys. Rev. Letters 75, 386

Waxman, E. 1995b, ApJ 452, L1

Wijers, R. *et al.* MNRAS 294, L13

Zatsepin, G.T. & Kuzmin, V.A. 1966, JETP Letters 4, 78